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Covariance Based Spectrum Detection for Cognitive Radio

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Abstract: ***Spectrum sensing is an essential problem in cognitive radio communication system. This paper presents covariance based spectrum sensing on the test bed of cognitive radio system. A series of tests show that the detection performance of Covariance Based spectrum sensing technique is not liable to be affected by the noise uncertainty in practical application and meets the need of the system primly. Furthermore, the performances of detection are also verified with different kinds of source signals. Simulations are carried out on MATLAB 2010a and system performance is measured based on probability of detection vs. SNR, Probability of false alarm, sensing time and modulation techniques respectively.***

Keywords: about four key words separated by commas**.**

1. Introduction

The requirement for higher data rates is growing as an effect of evolution from voice to multimedia transmission. Since the spectrum is scarce and static frequency allocation schemes cannot fulfill the demand of increasing number of high data rate devices. Hence innovative concepts which can offer new ways to utilize the available spectrum are needed. Cognitive radio has emerged as tempting solution of the aforementioned problem which allows opportunistic usage of frequency bands that are not occupied by the licensed users [1]. Cognitive Radios use the radio spectrum owned by other users. They perform radio environment examination, identify the unutilized bands and assigns these spectrum holes to unlicensed secondary users [2], [3]. In cognitive radio terminology, primary user refers to a user who is allocated the rights to use the spectrum. Secondary user refers to the users who try to use the frequency bands allocated to the primary user when the primary user is not using it. Spectrum Sensing, an essential component of the Cognitive Radio technology involves,

1) Identifying spectrum holes (white space) and,
2) When an identified spectrum hole is being used by the secondary user, to quickly detect the onset of primary transmission.

This needs to be done such that the guaranteed interference levels to the primary are maintained and there is efficient use of spectrum by the secondary. This involves detecting reliably, quickly and robustly, primary user’s signal.

For cognitive radios two typical scenarios have been identified. One is to use the white space in the TV broadcast channels [2], [4]. In this case one often knows the timings

When different TV broadcast channels are ON. A cognitive radio can use the channels which are free. During the time of broadcast at a channel also, a TV band can be used by cognitive users at locations where its transmission is weak, i.e., it cannot be used by a TV receiver at that place. For this a cognitive radio has to detect a spectral hole in space. If the cognitive radio is mobile then this can lead to detection of spectral hole in time also. In another scenario several IEEE 802.11 and Bluetooth devices may be sharing the ISM band (2.5 GHz). A device may use a channel when others are not using. This leads to detecting a white space in time where the channel may be available for use for a few msecs or secs [5]. The channel from the primary transmitter to a secondary user can be bad because of shadowing and time varying multipath fading. To alleviate this problem, Cooperative Spectrum Sensing [6], [7], [8], [9] is envisaged, whereby the spatial diversity inherent in radio environment is leveraged by allowing multiple secondary users to cooperate. This reduces the average time to detect the primary user. This in turn lowers the interference to the primary user (when it switches ON), while increasing the spectrum usage of the secondary (when the primary switches OFF).

Another important problem in spectrum sensing is the impact of modelling uncertainties, e.g. the noise distribution, noise power and/or channel gain may not be exactly known [4]. Because cognitive radios have to detect primary signals at very low SNR, these modelling uncertainties can cause an SNR wall, a level below which spectrum sensing fails to be robust to modelling uncertainties. More recently it is shown in 10 that if the primary user goes ON and OFF at different times one may be able to detect this change in a reliable and robust manner and then SNR wall can be breached. Of course in this case one is looking for spectral holes in time.

Energy detection method is a basic method, which requires knowledge of noise power but suffers from the noise uncertainty problem. Covariance based detection exploits space-time signal correlations that does not require the knowledge of noise and signal power. The covariance of signal and noise are generally different which can be used in the detection of licensed users. This paper proposes covariance based spectrum detection algorithm. The rest of this paper is organized as follows: Section-II gives literature of spectrum sensing algorithms followed by system model and proposed algorithm in section-III. Experimental setup and simulation results are given in section-IV. Finally section-V concludes this paper.

2. Literature Review

Spectrum sensing is active area of research since last few years, based on different requirements for implementation spectrum sensing techniques can be classified into three categories: (a) techniques requiring both signal and noise power related information, (b) techniques demanding only noise power related information (semi blind detection) and (c) techniques demanding no information on source signal or noise signal (totally blind detection). Matched filter [11] and cyclo-stationary feature detection [12] fall under category A. Energy Detection [11], wavelet based sensing [13] belong to category B, while covariance based detection [14] belong to category C. This paper implements covariance based spectrum sensing method.

3. System Model

Spectrum sensing alludes to identifying the unused spectrum and offering it without unsafe obstruction to other secondary users. In cognitive radio technology, primary users can be characterized as the users who have the most noteworthy need on the utilization of a particular part of the spectrum while secondary users have lower priority, and should not origin any intrusion to the primary users when using the channel. Spectrum sensing is still in its early stages of development. A number of various methods are proposed for identifying the presence signal in transmissions. In some another approaches, characteristics of the identified transmission are detected for deciding the signal transmission as well as identifying the type of signal [11]. The well known spectrum sensing techniques used are matched filter detection, energy detection, cyclostationary detection, wavelet detection and covariance detection.

3.1 Spectrum sensing problem

Spectrum sensing is a key part in cognitive radio communications as it must be performed before allowing unlicensed users to access a vacant licensed band. The essence of spectrum sensing is a binary hypothesis-testing problem:

$$H0: Primary\ user\ is\ absent$$
$$H1: Primary\ user\ is\ present \qquad (1)$$

The key metric in spectrum sensing are the probability of correct detection (P_d) and two types of error in spectrum sensor, the first error occurs when the channel is vacant (H_0) but the spectrum sensor can decide the channel is occupied, the probability of this event is the probability of false alarm (P_f), the second error when channel is occupied (H_1) the spectrum sensor can decide the channel is unoccupied, the probability of this event is probability of misdetection (P_m) [12].

$$P_d = prob\{Decision = {}^{H_1}/_{H_1}\}$$
$$P_f = prob\{Decision = {}^{H_1}/_{H_0}\}$$
$$P_m = prob\{Decision = {}^{H_0}/_{H_1}\} \qquad (2)$$

3.2 Covariance detection based spectrum sensing

Since the statistical covariance matrices or autocorrelations of the signal and noise are generally different, covariance-based signal detection methods can be used for spectrum sensing. By observing the fact that off diagonal elements of the covariance matrix of the received signal are zero when the primary user signal is not present and nonzero when it is present, two detection methods are possible: covariance absolute value detection and covariance Frobenius norm detection. The methods can be used for various signal detection and applications without knowledge of the signal, channel and noise power. The received signal samples under the two hypotheses are therefore respectively as follows [16]

$$\mathrm{H0}: x(n) = \eta(n)$$
$$\mathrm{H1}: x(n) = s(n) + \eta(n) \qquad (3)$$

Let $f(k), k = 0,1, \ldots K$ be normalized band pass filter applied to the signal.
Let

$$x'(n) = x(n) * f(n)$$
$$s'(n) = s(n) * f(n)$$
$$\eta'(n) = \eta(n) * f(n)$$

Then,

$$\mathrm{H0}: x'(n) = \eta'(n)$$
$$\mathrm{H1}: x'(n) = s'(n) + \eta'(n) \qquad (4)$$

Consider L samples and let

$$X(n) = [x'(n), x'(n-1), \ldots x'(-L(+1)]^T$$
$$S(n) = [s'(n), s'(n-1), . s'(n-L+1)]^T$$
$$\eta(n) = [\eta'(n), \eta'(n-1), . \eta'(n-L+1)]^T$$

Define a L x (L+K) matrix

$$H = \begin{bmatrix} f(0) & f(1) & \cdots & f(k) & 0 & \cdots & 0 \\ 0 & f(0) & \cdots & f(k-1) & f(k) & \cdots & 0 \\ \ddots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & f(0) & f(1) & \cdots & 0 \end{bmatrix} \qquad (5)$$

If $G = H(H^*)^H = Q^2$ then define
$R'_x = Q^{-1}R_xQ^{-1}$
Rx is the correlation matrix of x (n)
If there is no signal, then $R'_x = 0$. Hence the off diagonal elements of R'_x are all zeros. If there is signal and the signal samples are correlated, R'_x is not a diagonal matrix.
Let r_{nm} be the elements of R'_x. Let

$$K_1 = \frac{1}{L}\sum_{n=1}^{L}\sum_{m=1}^{L}|r_{nm}| \qquad (6)$$
$$K_2 = \frac{1}{L}\sum_{n=1}^{L}|r_{nn}| \qquad (7)$$
$$K_3 = \frac{1}{L}\sum_{n=1}^{L}\sum_{m=1}^{L}|r_{nm}|^2 \qquad (8)$$
$$K_2 = \frac{1}{L}\sum_{n=1}^{L}|r_{nn}|^2 \qquad (9)$$

The primary signal is considered to be present if $K_1 > \gamma K_2$, Covariance absolute value (CAV) detection or if $K_3 > \gamma K_4$. Covariance Frobenius norm (CFN) detection where γ is an appropriate value based on P_f.

The spectrum sensing can also be done using max-min eigen value detection and max eigen value detection methods. The essence of the eigen detection methods lies in the significant difference of the eigenvalue of the received signal covariance matrix when the primary user signal is present or not.

Experimental Setup & Results

To evaluate the performance of proposed spectrum sensing algorithm four test cases has been considered based on varying signal to noise ratio, modulation scheme, probability of false alarm and sensing time. Probability of detection is considered to be evaluation parameter. Simulations are carried out on MATLAB2010a. Simulation results and casewise performance are given as follows:

Case-1: Under first test scenario impact of varying signal to noise ratio on probability of detection has been evaluated. As given in fig-1 SNR values are varied in range of -12dB to 0dB and it is observed that with increasing signal power probability of detection increases.

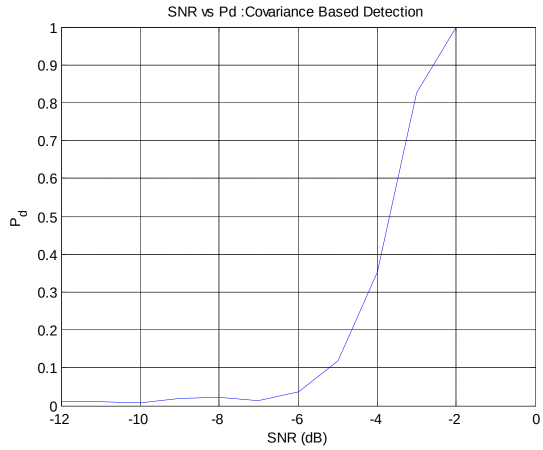

Figure 1: Signal to Noise ratio vs. probability of detection for covariance based detection algorithm

Case-2: In second test scenario impact of varying probability of false alarm on probability of detection has been evaluated. Value of probability of detection is calculated for varying P_f values from 0.01 to 0.1. Simulation result shows that probability of detection increases while increasing probability of false alarm.

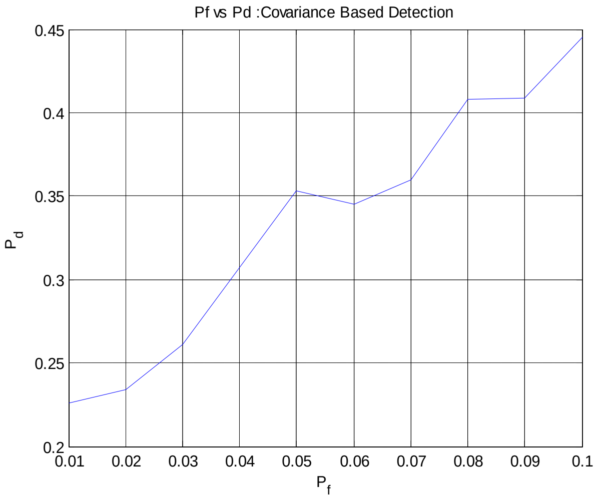

Figure 2: Probability of false alarm vs. probability of detection for covariance based detection algorithm

Case-3: Third test scenario is based on evaluating the impact of sensing time on probability of detection. The values of probability of detection are calculated on varying sensing time from 10 to 30 millisecond. Simulation result is given in figure-3.

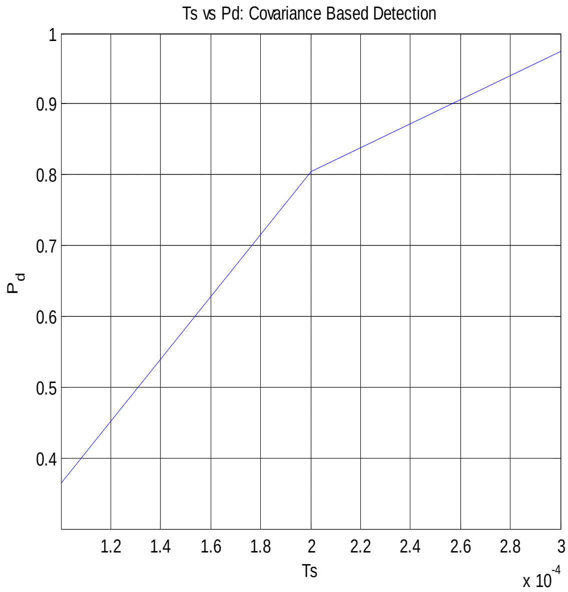

Figure 3: Sensing time vs. prob. of detection for covariance based detection algorithm

Case-4: The last case scenario was conducted to evaluate the impact of modulation techniques on probability of detection. Primary signal with all the variants of PSK modulation scheme is transmitted and covariance based approach is utilized for calculation of probability of detection. Simulation results show that BPSK performs well among the modulation schemes.

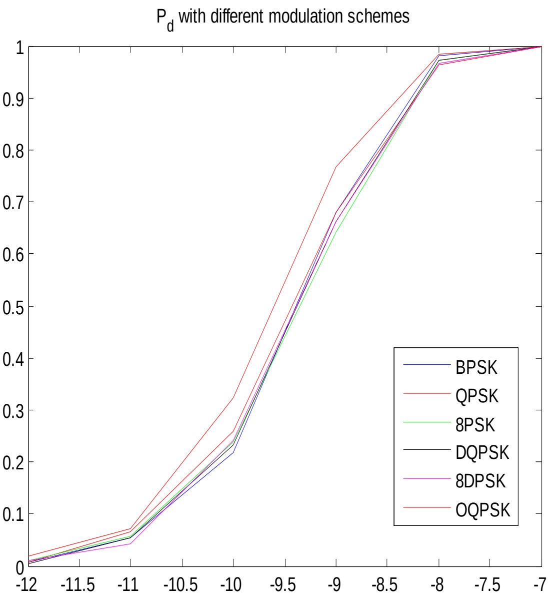

Figure 4: Probability of Detection vs Different Modulation Schemes

4. Conclusion

The main purpose of the research was to study the performance of covariance based detection algorithm for spectrum sensing in cognitive radio by drawing the curves between probability of false alarm vs. probability of detection, SNR vs. probability of detection, sensing time vs. probability of detection and modulation techniques vs. probability of detection. Simulation results show that our proposed scheme is capable of detect signal at SNR values upto -6dB.

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